FRICTION WELDED STRUCTURAL ASSEMBLY AND PREFORM AND METHOD FOR SAME

BACKGROUND OF THE INVENTION

1) Field of the Invention

[0001] The present invention relates to expanded structural assemblies and, more particularly, to an expanded structural assembly joined with a plurality of friction weld joints and to preforms and methods for forming such structural assemblies.

2) Description of Related Art

[0002] Expanded structural assemblies, and particularly honeycomb panels, are used in a variety of applications in the aerospace industry including, for example, flight control surfaces, acoustic suppression panels, aircraft flooring, other aircraft structural components, and the like. In addition, such expanded structural assemblies are also used in a variety of other industries and applications, including as structural members for automobiles and other vehicles. Honeycomb panels and other expanded structural assemblies advantageously provide a combination of high stiffness and low weight as compared to conventional panels formed from a solid material.

[0003] Conventional metal bonded aerospace honeycomb panels are produced by welding or brazing thin "foil like" core sheets to thicker outboard face sheets in a flat configuration. The resulting flat aerospace honeycombs can be used as flat structural panels or further creep-stretch formed into slightly curved shapes. Structural panels having more than a slightly curved configuration are typically more difficulty and expense to produce, e.g., requiring higher post-forming temperatures, expensive matched male/female dies for forming the panels, and/or high pressure restraint fixtures for forming the stiff conventional honeycomb into more complex shapes. Panel spring-back and core crush are also more likely

to occur when such severe forming operations are utilized. Panel spring-back can result in poor quality, poor fit, and an undesirable excessive spring pre-load condition after installation. Core crush, i.e., the buckling deformation and destruction of some of the cells of the panel that results from creep or stretch forming past the materials elastic limits, can severely reduce the panel's stiffness, strength, and life expectancy.

[0004] Cellular structure panels can also be formed from multi-sheet packs or preforms. However, such are hermetically sealed with conventional welding processes prior to superplastic forming, and the welding process can cause distortion, grain growth, contamination, loss of mechanical and corrosion properties, and the like. Packs or preforms conventionally welded and then superplastically formed often suffer from loss of ductility near the weld joints, which can result in cracking during or after the superplastic forming process. Further, superplastic forming of honeycomb-like structures that are made up of three or more sheets typically have welded joints that extend through only two of the sheets. These "partial penetration" joints are difficult to form by conventional welding techniques such as fusion or resistance welding. Reflective materials such as aluminum can also be very difficult to weld using laser welding because much of the laser energy is reflected away from the aluminum during processing. Therefore, aluminum requires greater amounts of power and heat input, and typically is characterized by a loss of material properties adjacent the weld joints.

[0005] U.S. Patent No. 6,537,682 to Cooligan, titled "Application of Friction Stir Welding to Superplastically Formed Structural Assemblies," describes a structural assembly formed by friction stir welding multiple structural members and thereafter superplastically forming the members to form the expanded assembly. The assembly can be formed by inflating the structural members in a die so that the assembly is formed to the shape of the die. The facing surfaces of the structural members can be partially covered with oxide to

prevent undesired thermo-compressing welding from occurring adjacent the friction stir weld joints. However, such a surface treatment does not guarantee that all of the cells will receive gas during forming and inflate to the desired shape. Further, when expanded, the structural members can deform near the friction stir weld joints, e.g., expanding the portions adjacent to the weld joints outward beyond the joints, thereby resulting in grooves at the weld joints and an uneven surface.

[0006] Thus, there exists a need for an improved expanded structural assembly and methods and preforms for forming the same. Preferably, the method should be capable of forming expanded structural assemblies of various shapes. Further, the structural assemblies should provide consistent expanding of the cells so that the assemblies are formed to the desired shape.

BRIEF SUMMARY OF THE INVENTION

[0007] The present invention provides a method for forming preforms and expanded structural assemblies therefrom. The preforms can include at least two structural members in a stacked relationship with elongate members disposed therebetween and extending generally along a path of at least one cell of the structural assembly and defining a passage through which fluid can be received during expanding of the cells. Further, the structural members of the preform can be connected by friction stir weld joints, some of which can extend only partially through the preform so that the preform defines cells that can be expanded.

[0008] According to one embodiment of the present invention, one or more core members can be positioned between first and second face members, and the face members can be friction welded to the core members with a friction welding tool that partially penetrates the core members. For example, the members can be friction stir welded with a rotating welding tool. If multiple core members are provided, friction stir weld joints can be formed entirely within the core members, and elongate members can be disposed between the

core members to extend generally along the paths of the cells. A periphery of the preform can also be friction welded with a tool that at least partially penetrates both of the face members. The periphery can be welded to define at least one fluid inlet in fluid connection with the cells.

[0009] At least two adjacent friction weld joints can be formed between adjacent cells, and the adjacent friction weld joints can have a combined width that is greater than a thickness of each of the structural members. The preform can be inflated by expanding the cells, e.g., to six-sided shapes that extend in a longitudinal direction so that the cells of the structural assembly define a honeycomb configuration. The preform can be expanded in a die cavity that defines a contour surface corresponding to a desired contour of the structural assembly so that expanding the cells urges the structural members outward against the die cavity. The contour surface can define a complex curve so that the structural assembly is formed to define the complex curve of the contour surface. According to one aspect of the invention, the preform is heated to a superplastic forming temperature such that the preform is superplastically formed during said inflating step. After inflating the preform, the resulting structural assembly can be quenched by circulating a coolant fluid therethrough. Alternatively, the preform can be cold stretch formed to the desired shape. The elongate members can also be removed from the structural assembly.

[0010] The present invention also provides a friction welded preform and an expanded structural assembly formed therefrom. The preform includes at least two structural members in a stacked relationship. The structural members can be formed of materials such as aluminum and aluminum alloys. A plurality of friction weld joints connect the structural members so that the structural members define at least one cell between the friction weld joints. A weld joint also extends at least partially around a periphery of the structural members and defines a fluid inlet fluidly connected to the at least one cell so that the preform

can be expanded by a pressurized fluid that is injected through the fluid inlet and into the cells. At least one elongate member can be disposed between the structural members of the preform so that the elongate member extends generally along a path of the at least one cell and maintains a passage between the structural members.

[0011] The preform and structural assembly can include first and second face members with at least one core member therebetween, and the elongate member can be disposed between the at least one core member and each of the first and second face members. A first of the friction weld joints can extend between the first face member and at least a portion of the core member, and a second friction weld joint can extend between the second face member and at least a portion of the core member so that the first friction weld joint can be inflated away from the second face member and the second friction weld joint can be inflated away from the first face member. Further, the preform and structural assembly can include a plurality of core members, and some of the friction weld joints can be disposed entirely between the core members such that the face members are configured to be inflated away from the core members. According to one aspect of the invention, the preform and the structural assembly define at least two adjacent friction weld joints between adjacent cells. The adjacent friction weld joints can have a combined width that is greater than a thickness of each of the structural members. At least one side of each cell of the structural assembly can be defined by the friction weld joints.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING(S)

[0012] Having thus described the invention in general terms, reference will now be made to the accompanying drawings, which are not necessarily drawn to scale, and wherein:

[0013] Figure 1 is a perspective view illustrating an expanded structural assembly formed according to one embodiment of the present invention;

[0014] Figure 2 is a perspective view illustrating the structural members of a preform for forming the structural assembly of Figure 1;

[0015] Figure 3 is a section view illustrating the structural members of Figure 2 as seen along line 3-3 of Figure 2;

[0016] Figure 4 is a section view illustrating the preform for forming the structural members of Figure 1;

[0017] Figure 4A is a perspective view illustrating a preform for forming a structural assembly according to another embodiment of the present invention, including weld joints having nonlinear weld connections;

[0018] Figure 5 is a section view illustrating the preform of Figure 4 configured in a die cavity for expanding;

[0019] Figure 6 is a perspective view of a structural assembly formed from the preform of Figure 4 according to another embodiment of the present invention;

[0020] Figure 7 is a section view of a preform for forming a structural assembly according to another embodiment of the present invention;

[0021] Figure 8 is an elevation view of the structural assembly formed from the preform of Figure 7;

[0022] Figure 9 is a section view of a preform for forming a structural assembly according to yet another embodiment of the present invention;

[0023] Figure 10 is an elevation view of the structural assembly formed from the preform of Figure 9; and

[0024] Figure 11 is a section view of a preform for forming a structural assembly according to still another embodiment of the present invention, the preform having a braze material disposed between the structural members.

DETAILED DESCRIPTION OF THE INVENTION

[0025] The present invention now will be described more fully hereinafter with reference to the accompanying drawings, in which some, but not all embodiments of the invention are shown. Indeed, this invention may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will satisfy applicable legal requirements. Like numbers refer to like elements throughout.

[0026] Referring now to the drawings and, in particular, Figure 1, there is illustrated an expanded structural assembly **10** according to one embodiment of the present invention. The structural assemblies **10** formed according to the present invention can be used in a variety of applications and structures, including aerospace applications such as flight control surfaces, acoustic suppression panels, aircraft flooring structures, other aircraft structural components, and the like. Alternatively, the structural assemblies **10** can be used in a variety of other industries and applications, including as structural members for automobiles, watercraft, other vehicles, building structures, and the like.

[0027] The structural assembly **10** illustrated in Figure 1 includes three structural members **12, 14, 16** and, in particular, a first face member **12**, a second face member **14**, and a core member **16** disposed therebetween so that first and second sides **18**, **20** of the core member **16** are directed toward the first and second face members **12, 14**, respectively. The structural members **12, 14, 16** are connected by weld joints **22, 24, 26** such as friction stir weld joints that extend partially or completely through the structural members **12, 14, 16**. In particular, first weld joints **22** connect the first face member **12** to the core member **16**, and second weld joints **24** connect the second face member **14** to the core member **16**. A peripheral weld joint **26**, connecting all of the structural members **12, 14, 16**, extends around

a peripheral portion **28** of the members **12, 14, 16**. The structural assembly **10** defines cells **30** between the members **12, 14, 16** and between the weld joints **22, 24, 26**.

[0028] Each of the weld joints **22, 24, 26** can be formed by various welding processes, such as friction stir welding. For example, Figures 2 and 3 illustrate the structural members **12, 14, 16** during formation of a preform **40** (Figure 4) that is subsequently used to form the structural assembly **10**. The first and second friction weld joints **22, 24** are formed by friction stir welding devices **50a, 50b** having rotatable pins **52a, 52b** that are configured to partially penetrate the structural members **12, 14, 16**. For example, the first friction stir welding device **50a** defines a shoulder **54a** and the pin **52a** extending therefrom. The shoulder **54a** and pin **52a** are rotated by a rotary actuator (not shown), and the pin **52a** is urged into the structural members **12, 16**. The pin **52a** is configured to extend through the first face member **12** and at least partially through the core member **16**. The welding device **50a** is then urged in a predetermined path along the structural members **12, 14, 16** to form the first friction stir weld joints **22**, which join the first face member **12** and the core member **16**, without joining those members **12, 16** to the second face member **14**. Similarly, the second friction stir welding device **50b** has a shoulder **54b** urged against the second face member **14** so that the pin **52b** extends through the second face member **14**, thereby forming the second friction stir welding joints **24** that extend at least partially through the core member **16** to join the second face member **14** and the core member **16** without joining those members **14, 16** to the first face member **12**. A third friction stir welding device **50c** has a pin **52c** that is structured to extend at least partially through each of the structural members **12, 14, 16** so that the resulting joint **26** at the periphery of the members **12, 14, 16** is a full-penetration joint which joins all of the members **12, 14, 16**. While separate friction stir welding devices **50a, 50b, 50c** are illustrated in Figures 2 and 3, it is appreciated that each of the weld joints **22, 24, 26** can be

formed using a single welding device, e.g., a welding device with an adjustable pin or shoulder to penetrate the members **12, 14, 16** to a selective depth as required.

[0029] Each friction stir welding device **50a, 50b, 50c** can be used to form a plurality of the friction stir weld joints **22, 24, 26,** and each of the weld joints **22, 24, 26** can be a multiple-pass weld joint comprised of multiple single-pass weld connections **22a, 24a, 26a** that are disposed adjacent one another so that each of the weld joints **22, 24, 26** has a combined width that is greater than a width of each of the individual connections **22a, 24a, 26a**. For example, as shown in Figures 2 and 3, the first and second welding devices **50a, 50b** can be urged along multiple adjacent paths so that the resulting multiple-pass weld joints **22, 24** have widths that are each approximately equal to the sum of the widths of the adjacent weld connections **22a, 24a,** respectively. Advantageously, the combined width of the weld joints **22, 24, 26** can be made as wide as desired, regardless of constraints on the width of the pins **52a, 52b, 52c** and the width of each individual weld connection **22a, 24a, 26a**. In some cases, the width of the weld joints **22, 24, 26** can be wider than the thickness of the structural members **12, 14, 16** that are being welded, and/or as wide as one side of the cells **30**. In some cases, the width of the weld joints **22, 24, 26** can be wider than the thickness of the structural members **12, 14, 16** that are being welded, and/or as wide as one side of the cells **30**.

[0030] Each of the individual weld connection **22a, 24a, 26a** can be substantially linear as shown in Figures 1 ad 2. Alternatively, one or more of the weld connections **22a, 24a, 26a** can define a nonlinear path, such as a sinusoidal or otherwise curved path, or a zigzag, sawtooth, or otherwise nonlinear path. For example, as shown in Figure 4A, each of the weld joints **22** includes two substantially linear weld connections **22a** and a nonlinear weld connection **22a'** defining a sinusoidal curve therebetween. In other embodiments, the weld joints **22, 24, 26** can include other configurations of linear and/or nonlinear weld connections **22a'**. For example, each weld joint **22, 24, 26** can include several substantially parallel

nonlinear weld connections similar to the sinusoidal weld connections **22a'** with or without linear weld connections **22a, 24a, 26a** proximate thereto. Further, the linear and/or nonlinear weld connections **22a, 22a'** can be partially overlapped. In either case, the use of nonlinear weld connections with or without the use of linear weld connections can increase the stiffness of the resulting structural assembly **10**

[0031] The first and second weld joints **22, 24** are disposed to define spaces therebetween so that the preform **40** defines the cells **30** that are subsequently expanded to form the structural assembly **10**. In addition, elongate members **51** such as cables or wires can be disposed between the structural members **12, 14, 16** in the cells **30** before the structural members **12, 14, 16** are welded. The elongate members **51** can extend in a continuous longitudinal direction between the structural members **12, 14, 16** so that the elongate members **51** maintain a space or passage **53** along the length of the cells **30** as shown in Figures 3 and 4. The elongate members **51** are preferably formed of a material having sufficient strength and heat resistance to maintain the passages **53** despite the forces and heat associated with friction stir welding or otherwise joining of the structural members **12, 14, 16**. For example, the elongate cables **51** can be formed of stainless steel wire, typically with a diameter of between about 0.05 inches and 0.25 inches. Generally, larger diameter wire can be used for thicker structural members **12, 14, 16** or configurations requiring increased force therebetween during welding. Smaller diameter wire can be used if the weld joints **22, 24, 26** are to be formed close together so that the structural members **12, 14, 16** are not excessively deformed by the presence of the elongate members **51** therebetween. Oxide films can also be provided on the surfaces of the structural members **12, 14, 16** adjacent the weld joints **22, 24, 26,** as described in U.S. Patent No. 6,537,682 to Colligan, the entirety of which is incorporated herein by reference.

[0032] The preform **40**, also referred to as a forming pack, can be expanded and formed to a desired configuration of the structural assembly **10**. In this regard, fluid connections **42** can be provided for supplying and, optionally, venting fluid from the cells **30** of the preform **40** and the structurally assembly **10**. As shown in Figure 2, the face members **12, 14** can be larger than the core member **16**, e.g., so that the face members **12, 14** extend beyond the core member **16** to form an overhang region **44**. The first and second weld joints **22, 24** can be formed co-extensive with the core member **16** so that the cells **30** end proximate to the overhang region **44**, and the cells **30** are therefore open to a space **46** defined between the face members **12, 14** in the overhang region **44**. The third weld joint **26**, which connects the face members **12, 14** and the core member **16** can extend around the periphery **28** of the preform **40** to close the space **46**. The fluid connections **42** extend through the third weld joint **26**, or the fluid connections **42** can be connected to the preform **40** at gaps provided in the third weld joint **26** so that the connections **42** are fluidly connected to the space **46** within the preform **40**. In other embodiments, fluid connections can be provided on opposite sides of the preform **40**, such as in the case of a large preform **40** defining long cells **30**, so that the fluid is provided to opposite sides of the preform **40**.

[0033] The preform **40** can be expanded by providing a pressurized fluid to the cells **30**, thereby inflating the cells **30** to a desired configuration. For example, as shown in Figure 5, the preform **40** can be positioned in a die cavity **60** defined by corresponding dies **62, 64**, and the fluid connections **42** can be connected to a pressurized fluid source **48**. The fluid source **48** can be configured to provide a gas, such as an inert gas at a pressure sufficient for inflating the cells **30**. The die cavity **60** can be defined by contoured surfaces of the dies **66, 68**, which correspond to a desired contour of the structural assembly **10**. For example, the contoured surfaces **66, 68** of the dies **62, 64** can define curves, angles, and the like. Further, the dies **62, 64** can define complex curvatures, i.e., contours having more than one axis of

curvature, such that the structural members **10** formed in the die cavity **60** define correspondingly complex curvatures. For example, the preform **40** can be expanded in the die cavity **60** shown in Figure 5 to form the structural assembly **10** of Figure 6, which includes face members **12, 14** that are curved about multiple axes of rotation.

[0034] According to one embodiment of the present invention, the preform **40** is superplastically formed to form the structural assembly **10**. As is known in the art, superplastic forming can be performed by heating the preform **40** to a superplastic forming temperature and subjecting the preform **40** to a pressure differential, i.e., in this case, a relatively high pressure within the cells **30** of the preform **40** and a low pressure in the die cavity **60** outside the preform **40**. Apparatuses and methods for superplastic forming are described in U.S. Patent Nos. 5,420,400 to Matsen; 5,994,666 to Buldhaupt, et al.; 4,811,890 to Dowling, et al.; and 4,181,000 to Hamilton, et al., each of which is incorporated herein in its entirety by reference.

[0035] The preform **40** can be heated, e.g., to a temperature sufficient for superplastic forming, by an induction heater that induces a current in one or more susceptors **70** in thermal communication with the preform **40**. The susceptors **70**, which can be disposed in the dies **62, 64**, can be configured to uniformly heat the preform **40** to a desired temperature. Such induction heating apparatuses and methods are described in U.S. Patent No. 4,622,445 to Matsen and U.S. Patent Nos. 6,566,635 and 6,180,932 to Matsen, et al., each of which is incorporated herein in its entirety by reference.

[0036] The preform **40** can alternatively be inflated or otherwise formed without a high temperature superplastic forming process. Instead, the preform **40** can be stretch formed at a relatively cool temperature, requiring no heating or heating only to a temperature below the superplastic forming temperature, i.e., cold stretch forming. For example, preforms **40** constructed of various aluminum alloys, such as Al 5083, can be stretch formed without first

providing substantial heating to the preforms **40**. Thus, preforms **40** formed of these aluminum alloys or other stretch-formable materials can be inflated in the die cavity **60** as described above without the use of the induction heater or other type of heater. The stretch forming of the preform **40** can result in cold working, thereby improving the strength or other material characteristics of the preform **40**.

[0037] For those preforms **40** that are heated in the die cavity **60** during forming, the resulting expanded structural assemblies **10** are preferably cooled before being removed from the die cavity **60**. For example, preforms **40** that are heated and superplastically formed in the die cavity **60** to form the structural assembly **10** can be quenched in the die cavity **60**. Quenching can be performed by circulating a quenching fluid through the die cavity **60**. The quenching fluid can be a liquid or a gas, such as cool air. The quenching fluid can be circulated through the expanded structural assembly **10**, e.g., into one or more of the gas connections **42**, through the cells **30** of the assembly **10**, and out of the assembly **10** through one or more of the gas connections **42**. The gas connections **42** can be provided on opposite ends of the structural assembly **10** for quenching, so that the quenching fluid can be delivered into the assembly **10** at one end thereof and released from the assembly **10** at the opposite end of the assembly **10**. In addition, the die cavity **60** can be opened, i.e., by lifting the first die **62** or lowering the second die **64**, so that air or other fluid can contact the outside of the structural assembly **10**, thereby further cooling the assembly **10**. The quenching fluid can be provided at a temperature that is sufficiently cool for quenching the hot structural assembly **10** and cooling the assembly **10** to a temperature at which the assembly **10** can be removed from the die cavity **60**. Further cooling can be performed after the structural assembly **10** is removed from the die cavity **60**, e.g., by circulating a fluid through the cells **30** of the assembly **10** and/or circulating a fluid outside the structural assembly **10**.

[0038] Other material processing operations can also be performed on the structural assembly **10**, including additional heat treatment operations. For example, the assembly **10** can be aged by increasing the temperature of the assembly **10** according to a predetermined temperature schedule, e.g., by heating the assembly **10** to an aging temperature of about 250° F and maintaining the assembly **10** at that temperature for a predetermined duration. Aging and other heat treatment operations can be performed while the assembly **10** is still in the die cavity **60** or after the assembly **10** has been removed therefrom.

[0039] For those preforms **40** that are cold stretched or otherwise formed at low temperatures, the resulting expanded structural assembly **10** can be removed from the die cavity **60** immediately after forming. Alternatively, material processing operations such as an aging operation can be performed on the assembly **10** while the assembly is still in the die cavity **60**.

[0040] Figure 7 illustrates a preform **40** that includes two core members **16a, 16b** disposed between the face members **12, 14**. The cells **30** between the face members **12, 14** and core members **16a, 16b** can be inflated or otherwise expanded to form the structural assembly **10**, as shown in Figure 8. The elongate members **51** can also be disposed between the structural members **12, 14, 16a, 16b** as the members **12, 14, 16a, 16b** are stacked to maintain the passages **53** along the length of the cells **30**. The preform **40** can be produced by first stacking the first and second core members **16a, 16b** and forming friction stir weld joints **25** that extend through the core members **25**. The first and second structural members **12, 14** can then be disposed on the first and second sides **18, 20** of the core members **16a, 16b**. The first structural member **12** can be welded to the first core member **16a** by forming partially penetrating friction stir weld joints **22** that extend through the first structural member **12** and through at least a portion of the first core member **16a**. The second structural member **14** can be welded to the second core member **16b** by forming partially penetrating

friction stir weld joints **24** that extend through the second structural member **14** and through at least a portion of the second core member **16b**. Alternatively, the first core member **16a** can first be welded to the first face members **12**, and the remaining members **14, 16b** can then be welded thereto, either individually or in combination. In any case, the welds joints **22, 24, 25** connect the adjacent structural members **12, 14, 16a, 16b** so that the cells **30** are defined between the weld joints **22, 24, 25**, and so that the cells **30** are defined between adjacent structural members **12, 14, 16a, 16b**, which can be deformed by inflation of the cells **30**. Each of the weld joints **22, 24, 25** can be a multiple-pass joint that includes any number of parallel adjacent weld connections. The face members **12, 14** can extend beyond one or more edges of the core members **16a, 16b** to define an overhang region **44** for defining the space **46** that communicates with the cells **30**, and the peripheral area **28** of the members **12, 14, 16a, 16b** can be joined with a weld joint (not shown) that extends therethrough to seal the space **46** and cells **30**.

[0041] It is appreciated that any number of structural members **12, 14, 16** can be welded to form a preform according to the present invention. Further, in some embodiments, the weld joints **22, 24, 25** can be disposed only partially through the preform **40**, e.g., between one of the face members **12, 14** and a portion of the core members **16** or between successively stacked core members **16**. For example, Figures 9 and 10 illustrate a preform **40** and an expanded structural assembly **10** formed therefrom. The preform **40** includes four core members **16a, 16b, 16c, 16d** disposed between the face members **12, 14**. Friction stir weld joints **22, 24, 25a, 25b, 25c** connect the core members **16a, 16b, 16c, 16d** and the face members **12, 14**. During formation of the preform **40**, the core members **16a, 16b, 16c, 16d** can be formed independently of the face members **12, 14** and then connected to the face members **12, 14**. Alternatively, the preform **40** can be formed by stacking the structural members **12, 14, 16a, 16b, 16c, 16d** in a different operational order, e.g., by successively

stacking the core members **16a, 16b, 16c, 16d** onto the first face member **12** and then connecting the second face member **14** to the core members **16a, 16b, 16c, 16d**.

[0042] Advantageously, the friction welding of the joints **22, 24, 25a, 25b, 25c** can refine the grain structure and improve the elongation properties of the structural members **12, 14, 16a, 16b, 16c, 16d** so that the members **12, 14, 16a, 16b, 16c, 16d** can be plastically deformed by cold stretch forming, superplastic forming, and the like. Further, as described above in connection with Figures 2 and 3, each of the friction weld joints **22, 24, 25a, 25b, 25c** can include multiple adjacent weld connections so that the adjacent weld connections define a combined multiple-pass weld joint that is wider than each of the individual weld connections. As shown in Figures 7 and 8, the combined width of the adjacent weld joints **22, 24, 25a, 25b, 25c** can be about as wide as one side of the cells **30**. By providing multiple adjacent weld connections, the bond between the structural members **12, 14, 16a, 16b, 16c, 16d** achieved by the weld joints **22, 24, 25a, 25b, 25c** can be made stronger and the risk of deformation of the face members **12, 14** can be reduced. For example, if the face members **12, 14** are provided in a relatively planar configuration, and stretch formed in the die cavity **30**, the core members **16a, 16b, 16c, 16d** can exert a tensile force between the face members **12, 14** while the preform **40** is being deformed. However, by forming wide weld joints, the tensile force associated with the core members **16a, 16b, 16c, 16d** can be distributed over a larger portion of the face members **12, 14**, thereby reducing the likelihood of undesirable local deformation of the face members **12, 14** occurring near the joints **22, 24, 25a, 25b, 25c**.

[0043] The elongate members **51** can be removed from the cells after forming, as shown in Figures 8 and 10. The expanded structural assembly **10** can also be cut, machined, or otherwise trimmed to a desired shape and size. Various features can be provided on the structural assembly **10**. For example, holes can be provided in the face members **12, 14** for receiving connector devices such as rivets, bolts, screws, and the like. Additionally, plates or

other members can be welded or otherwise connected to the face members **12**, **14** at regions where high stresses are anticipated, such as near holes in, or edges of, the face members **12**, **14**, where the structural assembly **10** is to be connected to other members, and other regions.

[0044] The structural members **12, 14, 16** of the present invention can be formed of a variety of materials, including various metals and metal alloys. Preferably, the preforms **40** and, hence, the structural assemblies **10** are formed of materials that can be friction welded to form the friction weld joints **22, 24, 25** before superplastic or stretch forming of the preforms **40**. Materials that can be friction stir welded and formed according to the present invention include, but are not limited to, aluminum, aluminum alloys, nickel alloys, and stainless steel. Further, the structural members **12, 14, 16** can be formed of so called "unweldable" materials, i.e., materials that are characterized by a high thermal conductivity and that typically quickly dissipate heat away from the weld joints and/or that exhibit cracking along the weld joint as a result of stresses caused by thermal expansion. Unweldable materials produce relatively weak weld joints when welded using conventional fusion welding processes and, thus, are for the most part not used in the construction of superplastically formed assemblies. Such materials can include aluminum, aluminum lithium, and titanium alloys such as Al 7000 series, Al 2195, and Ti 6Al-4V. Advantageously, many of these materials possess special corrosion, fatigue, strength, or ductility characteristics that are desired in certain applications. Further, the structural members **12, 14, 16** can be formed of similar or dissimilar materials, which are typically difficult or impossible to weld using conventional fusion or resistance welding processes.

[0045] In some embodiments, a braze material can also be provided between the structural members before the members are welded and formed. The braze material can then be melted, e.g., during the forming process, so that the braze material substantially fills any space between the structural members proximate to the weld joints **22, 24, 26**. For example,

as shown in Figure 11, the braze material can be disposed as foil in longitudinal strips **80** between the structural members **12, 14, 16** at the locations of the weld joints **22, 24, 26**. Subsequently, the strips **80** of the braze material is melted. For example, the strips **80** of the braze material can be melted in combination with the forming operation. In particular, the braze material can have a melting temperature that is less than the maximum temperature of the forming operation. In one embodiment, the forming operation includes a temperature increase at or near the end of the forming operation, so that the strips **80** are melted after the structural members **12, 14, 16** have been formed to the desired shape. The braze material preferably has a melting temperature that is lower than the melting temperature of the structural members **12, 14, 16**. For example, the braze material can be an alloy including one or more of aluminum, brass, copper, or zinc. Preferably, the braze material substantially fills the space between the adjacent structural members proximate to the weld joints **22, 24, 26**. For example, the braze material can fill the spaces between the adjacent weld connections **22a, 24a, 26a**. The braze material can increase the strength and stiffness of the resulting structural assembly **10** as well as increasing the assembly's resistance to fatigue and corrosion.

[0046] Many modifications and other embodiments of the invention set forth herein will come to mind to one skilled in the art to which this invention pertains having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the invention is not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.